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**MULTI-LAYER CIRCUIT BOARD****BACKGROUND OF THE INVENTION****1. Field of the Invention**

The invention relates to a multi-layer circuit board, more particularly to a multi-layer circuit board which can achieve impedance matching to result in reduced high speed signal reflection and reduced electromagnetic interference.

**2. Description of the Related Art**

A conventional multi-layer circuit board with eight wiring layers generally has a thickness of 1.6 mm or 1.2 mm. Reference is made to Figure 1, which shows a multi-layer circuit board with a thickness of 1.2 mm. As shown, the circuit board includes: first, second, third, fourth, fifth, sixth and seventh insulating substrates (F1), (F2), (F3), (F4), (F5), (F6), (F7) disposed sequentially one above the other; a first signal wiring layer (S1) disposed on one side of the first insulating substrate (F1) opposite to the second insulating substrate (F2); a first ground wiring layer (GND1) disposed between the first and second insulating substrates (F1), (F2); a second signal wiring layer (S2) disposed between the second and third insulating substrates (F2), (F3); a second ground wiring layer (GND2) disposed between the third and fourth insulating substrates (F3), (F4); a power wiring layer (POWER) disposed between the fourth and fifth insulating

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substrates (F4), (F5); a third signal wiring layer (S3) disposed between the fifth and sixth insulating substrates (F5), (F6); a third ground wiring layer (GND3) disposed between the sixth and seventh insulating substrates (F6), (F7); and a fourth signal wiring layer (S4) disposed on one side of the seventh insulating substrate (F7) opposite to the sixth insulating substrate (F6). The first, second, third, fourth, fifth, sixth and seventh insulating substrates (F1), (F2), (F3), (F4), (F5), (F6), (F7), the first, second, third and fourth signal wiring layers (S1), (S2), (S3), (S4), the first, second and third ground wiring layers (GND1), (GND2), (GND3), and the power wiring layer (POWER) are press-bonded to each other to form the circuit board with a thickness of about 1.2 mm. The first and fourth signal wiring layers (S1), (S4) are adapted to be mounted with electronic components (not shown) thereon.

Each of the first and seventh insulating substrates (F1), (F7) has a thickness (H4) of about 2.5 mil. Each of the second, fourth and sixth insulating substrates (F2), (F4), (F6) has a thickness (H3), (H1) of about 8 mil. Each of the third and fifth insulating substrates (F3), (F5) has a thickness (H2) of about 5 mil. Each of the first, third, fifth and seventh insulating substrates (F1), (F3), (F5), (F7) is made from a polyester prepreg. Each of the second, fourth and

sixth insulating substrates (F2), (F4), (F6) is made from a fibrous core material that contains paper or glass fibers. In this structure, the first signal wiring layer (S1) has a first resistance (Rs1) with respect to the first ground wiring layer (GND1). The second signal wiring layer (S2) has a second resistance (Rs2) with respect to the first and second ground wiring layers (GND1), (GND2). The third signal wiring layer (S3) has a third resistance (Rs3) with respect to the third ground wiring layer (GND3) and the power wiring layer (POWER). The fourth signal wiring layer (S4) has a fourth resistance (Rs4) with respect to the third ground wiring layer (GND3). The first and fourth resistances (Rs1), (Rs4) are about 44 ohms. The second and third resistances (Rs2), (Rs3) are about 55 ohms.

Figure 2 shows a multi-layer circuit board with a thickness of 1.6 mm. The 1.6 mm circuit board differs from the aforementioned 1.2 mm circuit board in that the thickness (H4) of the first and seventh insulating substrates (F1), (F7) is about 9.5 mil. As a result, the first and fourth resistances (Rs1), (Rs4) are about 76.4 ohms, and the second and third resistances (Rs2), (Rs3) are about 51 ohms. Due to their construction, the conventional circuit boards shown in Figures 1 and 2 suffer from the following drawbacks:

1. Serious high speed signal reflection

According to the standard theoretical values

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determined by Intel, the resistance between two adjacent wiring layers for a circuit board during high speed signal transmission is preferably within the range of  $55 \pm 10\% \Omega$ , i.e., between  $49.5\Omega$  and  $60.5\Omega$ .

5 However, the value of the first and fourth resistances (Rs1), (Rs4) of the aforementioned conventional 1.2 mm circuit board falls outside the preferred range recommended by Intel, and there is additionally a difference of about 11 ohms between the value of the first and fourth resistances (Rs1), (Rs4) and that of the second and third resistances (Rs2), (Rs3). Such a difference will result in an impedance mismatch. Thus, when a high speed signal is being transmitted through the conventional 1.2 mm circuit board and passes from the first or fourth wiring layer (S1) or (S4) to the second or third wiring layer (S2) or (S3), reflection of the signal will result, thereby adversely affecting signal transmission. Likewise, the value of the first and fourth resistances (Rs1), (Rs4) of the aforementioned conventional 1.6 mm circuit board falls outside the theoretical range, and there is a large difference of 25.4 ohms between the value of the first and fourth resistances (Rs1), (Rs4) and that of the second and third resistances (Rs2), (Rs3). The signal reflection problem is therefore very serious. The reflection index of high-speed signals for the 1.2 mm circuit board can be calculated as follows:

*Pattie*

$$\rho = \frac{Zl - Zo}{Zl + Zo} = \frac{Rs1 - Rs2}{Rs1 + Rs2} = 0.111$$

The reflection index for the 1.6 mm circuit board can be calculated in a similar manner to result in 0.199.

(2) Weakened magnetic flux counteraction: As reflection of high speed signals will generate standing waves, which will increase electromagnetic radiation of the high speed signals, the magnetic flux counteraction of the circuit board is weakened, thereby resulting in excessively high electromagnetic interference.

#### SUMMARY OF THE INVENTION

Therefore, the main object of the present invention is to provide a multi-layer circuit board which can achieve impedance matching to result in reduced high speed signal reflection and reduced electromagnetic interference.

Accordingly, a multi-layer circuit board of the present invention includes: first, second, third, fourth, fifth, sixth and seventh insulating substrates disposed sequentially one above the other; a first signal wiring layer disposed on one side of the first insulating substrate opposite to the second insulating substrate; a first ground wiring layer disposed between the first and second insulating substrates; a second signal wiring layer disposed between the second and third insulating substrates; a second ground wiring

layer disposed between the third and fourth insulating substrates; a power wiring layer disposed between the fourth and fifth insulating substrates; a third signal wiring layer disposed between the fifth and sixth insulating substrates; a third ground wiring layer disposed between the sixth and seventh insulating substrates; and a fourth signal wiring layer disposed on one side of the seventh insulating substrate opposite to the sixth insulating substrate. Each of the first and seventh insulating substrates has a thickness ranging from 2.5 to 7.5 mil. Each of the second and sixth insulating substrates has a thickness ranging from 3 to 13 mil. Each of the third and fifth insulating substrates has a thickness ranging from 3 to 15 mil. The fourth insulating substrate has a thickness ranging from 2 to 6 mil. The first signal wiring layer has a first resistance with respect to the first ground wiring layer. The second signal wiring layer has a second resistance with respect to the first and second ground wiring layers. The third signal wiring layer has a third resistance with respect to the third ground wiring layer and the power wiring layer. The fourth signal wiring layer has a fourth resistance with respect to the third ground wiring layer. The first, second, third and fourth resistances are within the range of 49.5 to 60.5 ohms.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Other features and advantages of the present invention will become apparent in the following detailed description of the preferred embodiments with reference to the accompanying drawings, of which:

5       Figure 1 is a schematic view of a conventional multi-layer ~~circuit~~ board with a thickness of about 1.2 mm;

10      Figure 2 is a schematic view of another conventional multi-layer ~~circuit~~ board with a thickness of about 1.6 mm;

15      Figure 3 is a schematic view of the first preferred embodiment of ~~a~~ multi-layer circuit board with a thickness of about 1.2 mm according to the present invention;

20      Figure 4 is a sectional view of the first preferred embodiment ~~in part~~;

25      Figure 5 is another sectional view of the first preferred embodiment ~~in part~~; and

30      Figure 6 is a schematic view of the second preferred embodiment of ~~a~~ multi-layer circuit board with a thickness of about 1.6 mm according to the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

35      Before the present invention is described in greater detail, it should be noted that like elements are denoted by the same reference numerals throughout the disclosure.

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Referring to Figures 3 to 5, the first preferred embodiment of a multi-layer circuit board 6 according to the present invention is shown to include first, second, third, fourth, fifth, sixth and seventh insulating substrates (L1), (L2), (L3), (L4), (L5), (L6), (L7) disposed sequentially one above the other; a first signal wiring layer (S1) disposed on one side of the first insulating substrate (L1) opposite to the second insulating substrate (L2); a first ground wiring layer (GND1) disposed between the first and second insulating substrates (L1), (L2); a second signal wiring layer (S2) disposed between the second and third insulating substrates (L2), (L3); a second ground wiring layer (GND2) disposed between the third and fourth insulating substrates (L3), (L4); a power wiring layer (POWER) disposed between the fourth and fifth insulating substrates (L4), (L5); a third signal wiring layer (S3) disposed between the fifth and sixth insulating substrates (L5), (L6); a third ground wiring layer (GND3) disposed between the sixth and seventh insulating substrates (L6), (L7); and a fourth signal wiring layer (S4) disposed on one side of the seventh insulating substrate (L7) opposite to the sixth insulating substrate (L6). The first, second, third and fourth signal wiring layers (S1), (S2), (S3), (S4) are generally made from copper foil, and the first and fourth signal wiring layers (S1), (S4) are adapted to

be mounted with electronic components (not shown) thereon.

The first, second, third, fourth, fifth, sixth and seventh insulating substrates (L1), (L2), (L3), (L4),  
5 (L5), (L6), (L7), the first, second, third and fourth signal wiring layers (S1), (S2), (S3), (S4), the first, second and third ground wiring layers (GND1), (GND2), (GND3), and the power wiring layer (POWER) are press-bonded to each other to form the circuit board  
10 6 with a thickness of about 1.2 mm.

During press-bonding of the circuit board 6, the second ground wiring layer (GND2) and the power wiring layer (POWER) are disposed to sandwich the fourth insulating substrate (L4). Then, the second signal wiring layer (S2) and the second ground wiring layer (GND2), and the third signal wiring layer (S3) and the power wiring layer (POWER) are disposed to sandwich the third and fifth insulating substrates (L3), (L5), respectively. The first ground wiring layer (GND1) and the second signal wiring layer (S2), and the third ground wiring layer (GND3) and the third signal wiring layer (S3) are disposed to sandwich the second and sixth insulating substrates (L2), (L6). Finally, the first signal wiring layer (S1) and the first ground wiring layer (GND1), and the fourth signal wiring layer (S4) and the third ground wiring layer (GND3) are disposed to sandwich the first and seventh insulating substrates  
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(L1), (L7) to constitute the 1.2 mm multi-layer circuit board 6.

According to the present invention, each of the first and seventh insulating substrates (L1), (L7) has a thickness (H4) ranging from 2.5 to 7.5 mil. Each of the second and sixth insulating substrates (L2), (L6) has a thickness (H3) ranging from 3 to 13 mil. Each of the third and fifth insulating substrates (L3), (L5) has a thickness (H2) ranging from 3 to 15 mil. The fourth insulating substrate (L4) has a thickness (H1) ranging from 2 to 6 mil. The first signal wiring layer (S1) has a first resistance (Rs1) with respect to the first ground wiring layer (GND1). The second signal wiring layer (S2) has a second resistance (Rs2) with respect to the first and second ground wiring layers (GND1), (GND2). The third signal wiring layer (S3) has a third resistance (Rs3) with respect to the third ground wiring layer (GND3) and the power wiring layer (POWER). The fourth signal wiring layer (S4) has a fourth resistance (Rs4) with respect to the third ground wiring layer (GND3). With the thicknesses of the insulating substrates (L1), (L2), (L3), (L4), (L5), (L6), (L7) controlled to be within the aforementioned ranges, the first, second, third and fourth resistances (Rs1), (Rs2), (Rs3), (Rs4) can be kept within the range of 49.5 to 60.5 ohms recommended by Intel for high speed signal transmission so as to achieve impedance

matching.

At least one of the first, third, fifth and seventh insulating substrates (L1), (L3), (L5), (L7) is made from a polyester prepreg. At least one of the second, 5 fourth and sixth insulating substrates (L2), (L4), (L6) is made from a fibrous core material that contains paper fibers or glass fibers.

According to the first preferred embodiment, each of the first and fourth signal wiring layers (S1), (S4) has a thickness of about 1.4 mil. Each of the second and third signal wiring layers (S2), (S3), the first, 10 second and third ground wiring layers (GND1), (GND2), (GND3), and the power wiring layer (POWER) has a thickness of about 0.7 mil. Each of the first and seventh insulating substrates (L1), (L7) has a preferred thickness (H4) of  $4.5 \pm 2$  mil, more preferably 15 4.5 mil. Each of the second and sixth insulating substrates (L2), (L6) has a preferred thickness (H3) of  $6 \pm 3$  mil, more preferably 6 mil. Each of the third and fifth insulating substrates (L3), (L5) has a preferred thickness (H2) of  $7 \pm 4$  mil, more preferably 20 7 mil. The fourth insulating substrate (L4) has a preferred thickness (H1) of 4 mil. Preferably, the thicknesses (H4) of the first and seventh insulating substrates (L1), (L7) are equal. The thicknesses (H3) 25 of the second and sixth insulating substrates (L2), (L6)

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are equal. The thicknesses ( $H_2$ ) of the third and fifth insulating substrates ( $L_3$ ), ( $L_5$ ) are equal.

The calculation of the approximate thickness of each of the insulating substrates ( $L_1$ ), ( $L_2$ ), ( $L_3$ ), ( $L_4$ ), ( $L_5$ ), ( $L_6$ ) and ( $L_7$ ) is explained in the following description.

Firstly, the value of the first resistance and fourth resistance ( $R_{s1}$ ), ( $R_{s4}$ ) is calculated using the following Formula (1) :

$$R_{s1}=R_{s4}=\frac{87}{\sqrt{E_R+1.41}} \ln\left\{\frac{5.98H_4}{0.8W+T_1}\right\} \dots\dots 1$$

wherein  $E_R$  is the dielectric coefficient and is equal to 4.5;  $H_4$  is the thickness of the first and seventh insulating substrates ( $L_1$ ), ( $L_7$ );  $W$  is the width of traces of the first and fourth signal wiring layers ( $S_1$ ), ( $S_4$ ) and is within the range of 2 to 8 mil and is equal to 5 mil in this preferred embodiment; and  $T_1$  is the thickness of the first and fourth signal wiring layers ( $S_1$ ), ( $S_4$ ) and is equal to 1.4 mil.

Next, the value of the second and third resistances ( $R_{s2}$ ), ( $R_{s3}$ ) is obtained using the following Formula (2) :

$$R_{s2}=R_{s3}=\frac{60}{\sqrt{E_R}} \ln\left\{\frac{4(H_3+H_2)}{0.67\pi W\left(0.8+\frac{T_2}{W}\right)}\right\} \dots\dots 2$$

wherein  $E_R$  is the dielectric coefficient and is equal to 4.5;  $H_2$  is the thickness of the third and fifth

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insulating substrates (L3), (L5); H3 is the thickness of the second and sixth insulating substrates (L2), (L6); T2 is the thickness of the second and third signal wiring layers (S2), (S3) and is equal to 0.7 mil; and 5 W is the width of traces of the second and third signal wiring layers (S2), (S3) and is within the range of 2 to 8 mil. In this preferred embodiment, W is equal to 5 mil.

$$2H_4 + 2H_3 + 2H_2 + 1H_1 + 2T_1 + 6T_2 \cong 1.2mm.....3$$

In addition, the total thickness of the circuit board should be equal to 1.2 mm (equivalent to about 47 mil) or within a tolerance range thereof, as expressed by the Formula (3). Based on the above Formula (3), the preferred value of thickness of each of the insulating substrates can be obtained. That is, when H1, the thickness of the fourth insulating substrate (L4) is within the range of 2 to 6 mil, it is preferably equal to 4 mil. When H2, the thickness of each of the third and fifth insulating substrates (L3), (L5) is within the range of 3 to 11 mil, it is preferably equal to 7 mil. When H3, the thickness of the second and sixth insulating substrates (L2), (L6) is within the range of 3 to 9 mil, it is preferably equal to 6 mil. When H4, the thickness of each of the first and seventh insulating substrates (L1), (L7) is within the range of 2.5 to 6.5 mil, it is preferably equal to 4.5 mil. As such, the first resistance (Rs1) of the

first signal wiring layer (S1) with respect to the first ground wiring layer (GND1) is equal to the fourth resistance (Rs4) of the fourth signal wiring layer (S4) with respect to the third ground wiring layer (GND3)

5 and is equal to 58 ohms, i.e.,  $Rs1=Rs4=58\Omega$ . The second resistance (Rs2) of the second signal wiring layer (S2) with respect to the first and second ground wiring layers (GND1), (GND2) is equal to the third resistance (Rs3) of the third signal wiring layer (S3) with respect to the power wiring layer (POWER) and the third ground wiring layer (GND3) and is equal to 52 ohms, i.e.,  $Rs2=Rs3=52\Omega$ . It is noted that these resistance values fall within the theoretical range of  $55\Omega \pm 10\%$ , and have a difference of only 6 ohms. As such, the reflection index  $\rho$  is reduced to 0.05, which is lower than the reflection index ( $\rho = 0.11$ ) in the prior art. Besides, the total thickness of the circuit board 6 fulfills Formula 3 ( $2H4+2H3+2H2+1H1+2T1+6T2$ ), and is equal to  $2 \times 4.5 \text{ mil} + 2 \times 6 \text{ mil} + 2 \times 7 \text{ mil} + 1 \times 4 \text{ mil} + 2 \times 1.4 \text{ mil} + 6 \times 0.7 \text{ mil} = 46 \text{ mil} \approx 1.2 \text{ mm}$  (within tolerance range).

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Figure 6 shows the second preferred embodiment of a multi-layer circuit board 6' according to the present invention. The difference between this embodiment and the previous embodiment is that the circuit board 6'

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has a thickness of about 1.6 mm, that each of the first and seventh substrates (L1'), (L7') has a preferred thickness of  $5.5 \pm 2$  mil, more preferably 5.5 mil, that each of the second and sixth insulating substrates (L2'), (L6') has a preferred thickness of  $10 \pm 3$  mil, more preferably 10 mil, and that each of the third and fifth insulating substrates (L3'), (L5') has a preferred thickness of  $11 \pm 4$  mil, more preferably 11 mil. The first signal wiring layer (S1) has a first resistance (Rs1') with respect to the first ground wiring layer (GND1). The second signal wiring layer (S2) has a second resistance (Rs2') with respect to the first and second ground wiring layers (GND1), (GND2). The third signal wiring layer (S3) has a third resistance (Rs3') with respect to the third ground wiring layer (GND3) and the power wiring layer (POWER). The fourth signal wiring layer (S4) has a fourth resistance (Rs4') with respect to the third ground wiring layer (GND3).

Under the condition that the sum according to Formula (3) is substantially equal to 1.6 mm (approximately 64 mil) and that the resistance values fall within the theoretical range recommended by Intel, the value of (Rs1'), (Rs4') and the value of (Rs2'), (Rs3') are first calculated using Formulae (1) and (2) so as to obtain the preferred thickness of each of the

insulating substrates. Of these parameters, the width of traces of the signal wiring layers is within the range of 2 to 8 mil, and is preferably 6 mil, as is mostly adopted for 1.6 mm circuit boards. It is found that  
5 when H1 is within the range of 2 to 6 mil, H1 is preferably 4 mil. When H2 is within the range of 7 to 15 mil, H2 is preferably 11 mil. When H3 is within the range of 7 to 13 mil, H3 is preferably 10 mil. When  
10 H4 is within the range of 3.5 to 7.5 mil, H4 is preferably 5.5 mil. As such, the first resistance ( $Rs1'$ ) is equal to the fourth resistance ( $Rs4'$ ) and is equal to 60 ohms,  
15 i.e.,  $(Rs1') = (Rs4') = 60\Omega$ . The second resistance ( $Rs2'$ ) is equal to the third resistance ( $Rs3'$ ) and is equal to 60 ohms, i.e.,  $(Rs2') = (Rs3') = 60\Omega$ . Both of these  
20 resistance values fall within the range of 49.5 to 60.5 ohms recommended by Intel. Besides, the reflection index is reduced to zero. Moreover, the thickness of the circuit board 6' according to Formula (3) is substantially equal to 1.6 mm:  
$$2H4 + 2H3 + 2H2 + 1H1 + 2T1 + 6T2 = 2 \times 5.5 \text{ mil} + 2 \times 10 \text{ mil} + 2 \times 11 \text{ mil} + 1 \times 4 \text{ mil} + 2 \times 1.4 \text{ mil} + 6 \times 0.7 \text{ mil} = 64 \text{ mil} \approx 1.6 \text{ mm}$$
  
(within tolerance range).

Accordingly, the multi-layer circuit board of the present invention has the following advantages:

25 1. Reduced high speed signal reflection

Since the resistances in both of the first and second



preferred embodiments fall within the recommended range of  $55\Omega \pm 10\%$ , and since the reflection indexes are substantially low as compared to those in the prior art, reflection of high speed signals can be significantly reduced or eliminated to make the circuit board very suitable for high speed signal transmission.

5           2. Reduced electromagnetic interference

As a result of reduced high speed signal reflection, generation of standing waves is not likely. Hence, 10 magnetic flux counteraction can be enhanced to reduce electromagnetic interference to meet current EMI standards.

15           3. Better adaptability for high speed signal layout

In view of the aforementioned advantages, the circuit board of this invention is suited for high speed signal layout to meet the current trend in the industry toward high speed signal development and to enhance market value of products and market competitiveness.

20           4. Enhanced layout time efficiency

Due to impedance matching, there is no need to alter the width of traces of the signal wiring layers, thereby improving the layout time efficiency.

While the present invention has been described in connection with what is considered the most practical 25 and preferred embodiments, it is understood that this invention is not limited to the disclosed embodiments but is intended to cover various arrangements included

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within the spirit and scope of the broadest interpretation so as to encompass all such modifications and equivalent arrangements.

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